

NJCAT TECHNOLOGY VERIFICATION
CM-75 INDUCTION GENERATOR BASED
COGENERATION MODULE

TECOGEN, INC.

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1. Introduction

1.1 New Jersey Corporation for Advance Technology (NJCAT) Program

NJCAT is a not-for-profit corporation to promote in New Jersey the retention and growth of technology-based businesses in emerging fields such as environmental and energy technologies. NJCAT provides innovators with the regulatory, commercial, technological and financial assistance required to bring their ideas to market successfully. Specifically, NJCAT functions to:

- Advance policy strategies and regulatory mechanisms to promote technology commercialization;
- Identify, evaluate, and recommend specific technologies for which the regulatory and commercialization process should be facilitated;
- Facilitate funding and commercial relationships/alliances to bring new technologies to market and new business to the state; and
- Assist in the identification of markets and applications for commercialized technologies.

The technology verification program specifically encourages collaboration between vendors and users of technology. Through this program, teams of academic and business professionals are formed to implement a comprehensive evaluation of vendor specific performance claims. Thus, suppliers have the competitive edge of an independent third party confirmation of claims.

Pursuant to N.J.S.A. 13:1D-134 et seq. (Energy and Environmental Technology Verification Program) the New Jersey Department of Environmental Protection (NJDEP) and NJCAT have established a Performance Partnership Agreement (PPA) whereby NJCAT performs the technology verification review and NJDEP certifies that the technology meets the regulatory intent and that there is a net beneficial environmental effect of the technology. In addition, NJDEP/NJCAT work in conjunction to develop expedited or more efficient timeframes for review and decision-making of permits or approvals associated with the verified/certified technology.

The PPA also requires that:

- The NJDEP shall enter into reciprocal environmental technology agreements concerning the evaluation and verification protocols with the United States Environmental Protection Agency, other local required or national environmental agencies, entities or groups in other states and New Jersey for the purpose of encouraging and permitting the reciprocal acceptance of technology data and information concerning the evaluation and verification of energy and environmental technologies; and
- The NJDEP shall work closely with the State Treasurer to include in State bid specifications, as deemed appropriate by the State Treasurer, any technology verified under the Energy and Environment Technology Verification Program.

1.2 Verification

On July 7, 2011, Tecogen, Inc., 45 First Avenue, Waltham, MA 02451 submitted a formal request for participation in the NJCAT Technology Verification Program. The technology proposed – The Tecogen CM-75 Cogeneration Module – is a 75kW compact system that produces both electricity and hot water onsite or close to the point where it is needed.

The request (after pre-screening by NJCAT staff personnel in accordance with the technology assessment guidelines) was accepted into the verification program. This verification report covers the evaluation based upon the performance claim of the vendor, Tecogen, that the CM-75 Cogeneration Module according to New Jersey Department of Environmental Protection Administrative Code 7:27-8.2(f), qualifies as an “insignificant source” of air emissions and consequently does not require an air permit.

This verification project primarily involved the evaluation of company literature and a third party laboratory test report to verify that the Tecogen CM-75 Cogeneration Module satisfies the performance claim made by Tecogen, Inc.

1.3 Applicant Profile

Tecogen manufactures natural gas engine-driven cogeneration modules and air conditioning systems for commercial and industrial customers. The cogeneration modules produce both electricity and hot water for use in building facilities. They reach high overall efficiencies by capturing and using heat from the engine that would otherwise be wasted, resulting in lower operating costs. The engine is equipped with a proprietary engine emission control technology that allows siting in areas with very stringent air quality requirements. Tecogen has an installed base of more than 2,100 units across 13 countries supported by an established network of engineering, sales and service personnel across the United States and abroad.

1.4 Key Contacts

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2. The Tecogen CM-75 Cogeneration Module

2.1 Technology Description

2.1.1 Engine-Generator Combined Heat and Power

Combined Heat and Power (CHP) recovers the waste energy of power generation and utilizes it as heat. CHP can describe large megawatt power plants or small-scale power generation technologies down to a few kilowatts. CHP is most efficient when the heating load is in close proximity to the electricity generation. Tecogen's 60-100 kW CHP products, driven by natural gas fueled reciprocating engines, can deliver more than 90% of the fuel's energy to a facility in the form of usable electric and thermal energy to offset utility expenditures. This can lead to significant energy cost savings for the end-user and a greatly reduced carbon footprint.

Customers who benefit most from cogeneration have long hours of operation with coincident electric and thermal loads. Traditional applications include hospitals and nursing homes, colleges and universities, health clubs and spas, hotels and motels, office and retail buildings, food and beverage processors, multi-unit residential buildings, laundries, ice rinks, swimming pools, factories, municipal buildings, and military installations. Tecogen currently has about 100 natural gas engine-driven cogeneration units operating in NJ, equipped with earlier generation emissions systems. Tecogen expects that with their new ultra-low emissions technology, combined with a streamlined permitting process through NJDEP, their market prospects should continue to grow and likely expand.

2.1.2 Tecogen CM-75 Model

The CM-75's prime mover is a GM 7.4L naturally-aspirated V8 engine driving an induction generator at approximately 1800 rpm. The CM-75 is equipped with Tecogen's latest advances in exhaust gas treatment technology developed to satisfy the most aggressive emissions limits known to exist in the nation for stationary power internal combustion engines. The exhaust gas treatment system consists of a novel two-stage approach that uses an upstream Süd-Chemie three-way catalyst assembly to perform the bulk of all criteria pollutant reductions (NO_x, CO, and HCs), followed by air injection into the exhaust stream to serve a second-stage oxidation catalyst assembly to further reduce CO and HCs. The enhanced oxidation reactions provided by the air-assisted, second-stage catalyst produce the final effect for the ultra-low emissions demonstrated by the CM-75.

Tecogen produces several cogeneration modules (models) using the same engine platform and exhaust gas treatment strategy. All of these models are driven by the same 7.4L naturally-aspirated V8 engine and all benefit from the same precise closed-loop air/fuel ratio control provided by Tecogen's embedded electronics and oxygen sensors located before and after the first-stage three-way catalyst assembly. Differences in full-load engine output between the models are compensated by changes in the volume of catalyst material. The models that are viewed as being in a common family are Tecogen's:

- CM-60 (60 kW CHP)

- CM-75 (75 kW CHP)
- INV-100 (100 kW CHP)

The CM-60 is simply a derated CM-75, with identical mechanical and electronic features. In the INV-100, the engine is coupled to a permanent magnet generator, instead of to a traditional induction-type electrical generator as in the CM-60 and CM-75. The electrical power from the INV-100's generator is then fed through an inverter, which conditions the power to make it suitable for interconnection to the local utility grid, regardless of the engine and generator speed. The flexibility to run the engine at any speed enables an increase of peak continuous power to 100 kW, increases engine efficiency at part load conditions, and enables black-start (stand-alone) stand-by operation, a mode not available with induction generator products.

2.2 New Jersey Administrative Code

According to New Jersey Administrative Code (N.J.A.C.) section 7:27-8.2(c), any equipment or source operation that may emit one or more air contaminants, except carbon dioxide (CO₂), directly or indirectly into the outdoor air and belongs to one of the categories listed below (e.g. any stationary reciprocating engine with a maximum rated power output of 37 kW or greater, used for generating electricity, not including emergency generators), is a significant emissions source (and therefore requires a preconstruction permit and an operating certificate), unless it is exempted from being a significant source pursuant to (d), (e) or (f) below:

N.J.A.C. section 7:27-8.2(f)1.ii provides for “any piece of electric generating equipment, other than a fuel cell system or a microturbine, with less than 500 kilowatts generating capacity and that has been verified according to the requirements in (f)2 below to emit less than:

- (1) 0.40 pounds of NO_x per megawatt hour;
- (2) 0.25 pounds of CO per megawatt hour;
- (3) 0.10 pounds of PM per megawatt hour; and
- (4) 0.01 pounds of SO₂ per megawatt hour”,

to not be classified as a significant source.

2.3 Technical Performance Claim

Claim – The Tecogen CM-75 Cogeneration Module fired with natural gas when operated at 100% load has demonstrated by source emission testing that it emits less than 1) 0.40 pounds of NO_x per megawatt hour, 2) 0.25 pounds of CO per megawatt hour, 3) 0.10 pounds of PM per megawatt hour; and 4) 0.01 pounds of SO₂ per megawatt hour and, therefore, it is not a significant source of emissions in accordance with N.J.A.C. 7:27-8.2(f)1.ii.

3. Technology Evaluation

3.1 Introduction

Almega Environmental & Technical Services (Almega), 5251 McFadden Avenue, Huntington Beach, CA 92649, was contracted by Tecogen, Inc. to conduct stationary source emissions

testing of the natural gas fired CM-75 cogeneration module located at the City of San Fernando Regional Swimming Pool, 208 Park Avenue, San Fernando, California. The purpose of the test was to measure emissions from the CM-75 for oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), oxygen (O₂), carbon dioxide (CO₂), and particulate matter (PM). The testing was conducted to demonstrate that the CM-75 is not a significant source of emissions in accordance with N.J.A.C. 7:27-8.2(f)1.ii. Additionally, testing was conducted for volatile organic compounds (VOC) as total gaseous non-methane organics (TGNMO) and reported for informational purposes. Testing was conducted on July 29, 2011.

3.2 Test Methodologies

The test parameters and test methods used for the emission test program are specified in Table 1 and the sampling and analytical procedures described in Appendix A.

Table 1 Test Parameters and Test Methods

PARAMETER	LOCATI ON	TEST METHOD	# OF TEST RUNS	TEST TIME
Oxides of Nitrogen (NO _x)	Outlet exhaust	EPA Method 7E	3	64 min.
Carbon Monoxide (CO)	Outlet exhaust	EPA Method 10	3	64 min.
O ₂ /CO ₂	Outlet exhaust	EPA Method 3A	3	64 min.
Sulfur Dioxide (SO ₂)	Outlet exhaust	SCAQMD Method 6.1	1	240 min
Total Particulate Matter	O Outlet exhaust	EPA Method 5	1	240 min.
VOC, as TGNMO	Outlet exhaust	SCAQMD Method 25.3	1	60 min.
Stack Traverse Points and Stack Gas Flow Rate	Outlet exhaust	EPA Methods 1A, 2C	1	240 min
Molecular Weight and Excess Air	Outlet exhaust	EPA Method 3A	1	240 min
Moisture content	Outlet exhaust	EPA Method 4	1	240 min

SCAQMD – South Coast Air Quality Management District

The testing was conducted after the arrival of Almega’s test personnel and set-up of test equipment. The CM-75 was operated by plant personnel during testing activities. The testing was conducted at the engine’s maximum (100% load) operating conditions for the electrical generation (75kW). The exhaust of the engine is routed to the exhaust gas treatment system (EGTS) before being vented to the atmosphere. Sampling was performed at the outlet of the treatment system. Testing was conducted as specified in the reference methods. No unusual operating conditions were noted during the test periods.

3.3 Sampling Locations

Samples were collected at the outlet of the exhaust gas treatment system of the CM-75 which is located on the roof. A pipe extension was attached to the exhaust pipe of the unit so that the sampling locations would meet the minimum testing requirements of EPA Method 1A. The following are the emission sampling and gas velocity measurement location dimensions:

Sampling Location Configuration – Emission Sampling Probe (PM):	
Upstream	144 in. (24.0 duct diameter)
Downstream	148 in. (24.7 duct diameter)
Port Length	0 in. (measured from outside wall)
Port Inside Diameter	2 in.
Number of Sampling Ports	2 (located at 90° intervals)
Stack Diameter	6 in. (internal diameter)

Sampling Location Configuration – Gas Velocity Profile	
Upstream	216 in. (36 duct diameter)
Downstream	76 in. (12.7 duct diameter)
Port Length	0 in. (measured from outside wall)
Port Inside Diameter	1 in.
Number of Sampling Ports	2 (located at 90° intervals)
Stack Diameter	6 in. (internal diameter)
Sampling Location Configuration – Emission Sampling Probe (CEMS):	
Upstream	197 in. (32.8 duct diameter)
Downstream	95 in. (15.8 duct diameter)
Port Length	0 in. (measured from outside wall)
Port Inside Diameter	1 in.
Number of Sampling Ports	2 (located at 90° intervals)
Stack Diameter	6 in. (internal diameter)

Sampling Location Configuration – Emission Sampling Probe (SO₂):	
Upstream	192 in. (32 duct diameter)
Downstream	100.5 in. (16.8 duct diameter)
Port Length	0 in. (measured from outside wall)
Port Inside Diameter	2 in.
Number of Sampling Ports	2 (located at 90° intervals)
Stack Diameter	6 in. (internal diameter)

All above sampling locations comply with the requirements of EPA Method 1A/SCAQMD 1.2.

3.4 Test Chronology

The testing was conducted during the periods listed below:

Parameter Measurement	Test Date	Time	Location	Run No.
EPA Method 5-PM	7/29/11	13:00-17:10	Exhaust of EGTS	Run 1
SCAQMD Method 6.1-SO ₂	7/29/11	13:00-17:00	Exhaust of EGTS	Run 1
SCAQMD Method 25.3-VOC	7/29/11	13:00-14:00	Exhaust of EGTS	Run 1
EPA Methods 7E/10/3A (NO _x /CO & O ₂ /CO ₂)	7/29/11	13:00-14:06	Exhaust of EGTS	Run 1
	7/29/11	14:35-15:41	Exhaust of EGTS	Run 2
	7/29/11	16:10-17:16	Exhaust of EGTS	Run 3

EGTS – Exhaust Gas Treatment System

4. Verification Procedures: Technology System Performance

4.1 Data Analysis

Almega applies stringent quality assurance and quality control (QA/QC) procedures to ensure the validity of measurements for all test methods. Almega's QA/QC procedures follow guidelines

from the "Quality Assurance Handbook for Air Pollution Measurement Systems," Volume I through III. For more discussion on Almega's QA/QC procedures see Appendix B.

4.2 Test Results

Test results are summarized in Table 2 and detailed test results are presented in Table 3 followed by a discussion of the results.

Table 2 Summary of Test Results

Parameter	Units	Average Test Results	NJDEP Limit(s)
Test Date:	m/d/y	7/29/2011	
Start Time:	hh:mm	13:00	
End Time:	hh:mm	17:16	
Stack Gas Flow*	dscfm	137	
<u>O₂ Concentration</u>			
Concentration, measured	%	<1.00	
<u>CO₂ Concentration</u>			
Concentration, measured	%	11.86	
<u>NO_x Emissions</u>			
Concentration, measured	ppmv	2.08	
Concentration @ 15% O ₂	ppmv	<0.617	
Emission Rate	lb/hr	0.0021	
Emission Rate	lb/MW-hr	0.028	0.40 lb/MW-hr
<u>CO Emissions</u>			
Concentration, measured	ppmv	<5.00	
Concentration @ 15% O ₂	ppmv	<1.48	
Emission Rate	lb/hr	<0.0030	
Emission Rate	lb/MW-hr	<0.040	0.25 lb/MW-hr
<u>Particulate Emissions</u>			
Total PM by weight	mg	2.53	
Concentration	gr/dscf	0.000227	
Emission Rate	lb/hr	0.000266	
Emission Rate	lb/MW-hr	0.0035	0.10 lb/MW-hr
<u>SO₂ Emissions</u>			
Concentration	mg/dscm	0.074	
Concentration	ppmv	0.029	
Emission Rate	lb/hr	0.000039	
Emission Rate	lb/MW-hr	0.00053	0.01 lb/MW-hr
<u>VOC Emissions (TGNMO as Methane)</u> ⁽¹⁾			
Concentration	ppmv	<13.39	
Concentration @ 15% O ₂	ppmv	<3.86	
Emission Rate	lb/hr	<0.0046	
Emission Rate	lb/MW-hr	<0.062	
<u>VOC Emissions (TGNMO as Methane)</u> ⁽²⁾			
Concentration	ppmv	11.84	
Concentration @ 15% O ₂	ppmv	3.42	
Emission Rate	lb/hr	0.0040	
Emission Rate	lb/MW-hr	0.053	
<u>Process Data</u>			
Kilowatt Rating	Rated KW	75	
Actual Generator KW	KW	75	
Percent of KWH	Percent	100	
Fuel Usage	scfm	18.4	
Catalyst Temperature	degree F	1,063	
O ₂ Sensor mV Reading	mV	722	

"<" – Concentration was below the 20% of analytical range, reporting limit is reported per Method.

(1) Non-Condensable fraction was not detected, reporting limit is reported & added to the detectable condensable fraction.

(2) Non-Condensable fraction of the reported values were lower than the reporting limit.

Stack flow was measured via EPA Method 5. All test results were calculated at standard conditions of 68 °F and 29.92 in Hg.

Table 3 Test Results by Run

Parameter	Units	TEST RESULTS			
		Run 1	Run 2	Run 3	Average
Test Date:	m/d/y	7/29/11	7/29/11	7/29/11	7/29/2011
Start Time:	hh:mm	13:00	14:35	16:10	13:00
End Time:	hh:mm	14:06	15:41	17:16	17:16
Stack Gas Flow*	dscfm	137	--	--	137
<u>O₂ Concentration</u>					
Concentration, measured	%	<1.00	<1.00	<1.00	<1.00
<u>CO₂ Concentration</u>					
Concentration, measured	%	11.87	11.86	11.84	11.86
<u>NO_x Emissions</u> Concentration,					
measured Concentration	ppmv	2.10	2.03	2.11	2.08
@ 15% O ₂	ppmv	<0.624	<0.601	<0.627	<0.617
Emission Rate	lb/hr	0.0021	0.0020	0.0021	0.0021
Emission Rate	Lb/MW-hr	0.0284	0.0267	0.0284	0.028
<u>CO Emissions</u> Concentration,					
measured Concentration	ppmv	<5.00	<5.00	<5.00	<5.00
@ 15% O ₂	ppmv	<1.48	<1.48	<1.48	<1.48
Emission Rate	lb/hr	<0.0030	<0.0030	<0.0030	<0.0030
Emission Rate	Lb/MW-hr	<0.0400	<0.0400	<0.0400	<0.040
<u>Particulate Emissions (13:00-17:10)</u>					
Total PM by weight	mg	2.53	--	--	2.53
Concentration	gr/dscf	0.000227	--	--	0.000227
Emission Rate	lb/hr	0.000266	--	--	0.000266
Emission Rate	Lb/MW-hr	0.00355	--	--	0.0035
<u>SO₂ Emissions (13:00-17:00)</u>					
Concentration	mg/dscm	0.074	--	--	0.074
Concentration	ppmv	0.029	--	--	0.029
Emission Rate	lb/hr	0.0000394	--	--	0.000039
Emission Rate	Lb/MW-hr	0.000525	--	--	0.00053
<u>VOC Emissions (TGNMO as Methane) ⁽¹⁾</u>					
Concentration	ppmv	<13.39	--	--	<13.39
Concentration @ 15% O ₂	ppmv	<3.86	--	--	<3.86
Emission Rate	lb/hr	<0.0046	--	--	<0.0046
Emission Rate	Lb/MW-hr	<0.062	--	--	<0.062
<u>VOC Emissions (TGNMO as Methane) ⁽²⁾</u>					
Concentration	ppmv	11.84	--	--	11.84
Concentration @ 15% O ₂	ppmv	3.42	--	--	3.42
Emission Rate	lb/hr	0.0040	--	--	0.0040
Emission Rate	Lb/MW-hr	0.053	--	--	0.053
<u>Process Data</u>					
Kilowatt Rating	Rated KW	75	75	75	75
Generator Output	KW	75	75	75	75
Percent of KWH	Percent	100	100	100	100
Fuel Usage	scfm	18.5	18.2	18.5	18.4
Catalyst Temperature	degree F	1,063	1,064	1,064	1,063
O ₂ mv Reading	mv	720	720	725	722

"<". Concentration was below the 20% of analytical range, reporting limit is reported per Method.

⁽¹⁾ Non-Condensable fraction was not detected, reporting limit is reported & added to the detectable condensable fraction.

⁽²⁾ Non-Condensable fraction of the reported values were lower than the reporting limit.

* Stack flow was measured via EPA Method 5. All test results were calculated at standard conditions of 68°F and 29.92 in Hg.

Exhaust Gas Treatment

- The average measured NO_x concentration was 2.08 ppmv. The corresponding NO_x emission rate was 0.028 lb/MW-hr which is significantly (more than an order of magnitude) less than the limit of 0.40 lb/MW-hr imposed by NJDEP.
- The average measured CO concentration was less than the minimum quantitation limit of the CEMS according to Method 7E (The reporting limit for CO is <5.0 ppmv which is 20% of the calibrated range of 25 ppmv full-scale). The corresponding CO emission rate was <0.040 lb/MW-hr which is less than the limit of 0.25 lb/MW-hr imposed by NJDEP.
- The measured total particulate matter (PM) concentration was 0.000227 grains/dscf as determined by EPA Method 5. The corresponding PM emission rate was 0.0035 lb/MW-hr which is significantly less than the limit of 0.10 lb/MW-hr imposed by NJDEP.
- The measured sulfur dioxide (SO₂) concentration was 0.074 mg/dscm and 0.029 ppmv as determined by SCAQMD Method 6.1. The corresponding SO₂ emission rate was 0.00053 lb/MW-hr which is significantly less than the limit of 0.01 lb/MW-hr imposed by NJDEP.
- The measured VOC concentration, TGNMO as methane, was <13.39 ppmv. The corresponding VOC emission rate, calculated as methane, was < 0.0046 lb/hr and <0.062 lb/MW-hr. The non-condensable fraction was not detected and the reporting limit of 2.0 ppmv was reported and added to the detectable condensable fraction.
- The VOC concentration below the reporting limit was also reported for qualitative purposes. The measured VOC concentration, TGNMO as methane, was reported as 11.84 ppmv, which included the analysis values observed below the reporting limit for non-condensable fraction. This corresponding VOC emission rate, calculated as methane, was 0.0040 lb/hr and 0.053 lb/MW-hr.
- Relative precision between the duplicate VOC analyses was less than 20%; therefore, an average result was reported. The VOC emission was reported for information purposes.

Others

- All measured concentrations were corrected for bias zero and bias calibration drifts according to EPA M7E.
- All instruments performed properly during testing and their performance specifications were within the allowable limits specified in Method 7E.
- The reference method CEMS probe was traversed across the stack for the representative sampling.

- The NO₂ to NO converter efficiency check was performed on the reference method NO_x analyzer. The average converter efficiency was greater than 90%.
- Cyclonic flow check was performed prior to sampling. No cyclonic flow was found.
- The dew point of the gas exiting the conditioner system was maintained below 37°F.
- The measured CO and O₂ concentrations fell below the quantifiable range of the reference method analytical range; hence, the reporting limit (20% of analytical range) was reported per Method 7E.
- All test results were calculated according to EPA standard conditions of 68 °F and 29.92 inches of mercury.
- The reported moisture for the flow rate calculation was based on SCAQMD Method 6.1 sampling train.
- Three 64 minute test runs were conducted for NO_x, CO, O₂ and CO₂ and an average result was reported. The reported emissions for particulate matter and SO₂ were based on a single 240 minute test run.

Testing was performed as specified in the reference methods. No modifications to proposed sampling and analysis procedures other than those noted above were required.

4.3 Data Extension to All Tecogen's 7.4L V8 Engine Cogeneration Models

Tecogen produces several cogeneration modules (models) using the same engine platform and exhaust gas treatment strategy and sells these products nationwide with optional emissions control features based on the market being served. All of these models are driven by the same 7.4L naturally-aspirated V8 engine and all benefit from the same precise closed-loop air/fuel ratio control provided by Tecogen's embedded electronics and oxygen sensors located before and after the first-stage three-way catalyst assembly. Differences in full-load engine output between the models are compensated by changes in the volume of catalyst material. For New Jersey CHP product sales, Tecogen intends to offer its most aggressive after-treatment configuration (the one tested for this verification) that was developed for markets with more severe emissions requirements. The exceptionally low results from the Almega CM-75 emissions source test provide an indication of the over-sizing of the catalyst system for compliance with New Jersey emission limits.

5. Performance Claim Verification

The Almega testing has demonstrated that the Tecogen CM-75 natural gas-fired cogeneration module has carbon monoxide emissions well below the emission limit of 0.25 Lb/MW-Hr, has NO_x emissions significantly below the emission limit of 0.4 Lb/MW-Hr, has PM emissions significantly below the emission limit of 0.10 Lb/MW-Hr and has sulfur dioxide emissions

significantly below the emission limit of 0.01 LB/KW-Hr when operated at 100% load. Hence Tecogen's technical performance claim that **“The Tecogen CM-75 Cogeneration Module fired with natural gas when operated at 100% load has demonstrated by source emission testing that it emits less than 1) 0.40 pounds of NO_x per megawatt hour, 2) 0.25 pounds of CO per megawatt hour, 3) 0.10 pounds of PM per megawatt hour; and 4) 0.01 pounds of SO₂ per megawatt hour and, therefore, it is not a significant source of emissions in accordance with N.J.A.C. 7:27-8.2(f)1.ii”** has been verified.

The Tecogen 7.4L naturally-aspirated V8 engine driven cogeneration model family (CM-60, CM-75, INV-100) all benefit from the same precise closed-loop air/fuel ratio control provided by Tecogen's embedded electronics and oxygen sensors located before and after the first-stage three-way catalyst assembly. Exhaust catalysts for each model are sized based on the maximum exhaust gas flow rate for the model, which inherently compensates for variable engine speeds between models. This maintains space velocities (time exhaust gases are in contact with catalytic material) at comparable values and ensures abnormally high contact times between the exhaust and the catalyst across the models.

The space velocity comparisons between the CM-60, CM-75, and INV-100 family of products show the CM-75 to be the worst-case scenario of the three, with the highest space velocity, or lowest contact time between pollutants and catalyst material at full load. Thus the CM-75 was a suitable model for generating emissions characteristic data for all three CHP product configurations using the 7.4L engine.

Therefore, sound engineering judgment leads to the conclusion that the exhaust gas emissions demonstrated during the testing of the CM-75 cogeneration module at the City of San Fernando Regional Swimming Pool are a conservative representation of CM-60 and INV-100 emissions using the same engine platform and exhaust gas treatment strategy and approach. **Consequently, all three cogeneration models are not a significant source of emissions in accordance with N.J.A.C. 7:27-8.2(f)1.ii.**

6. Net Environmental Benefit

Engine-driven power cogeneration equipment can provide a source of clean and reliable electricity and heat. Since buildings in the United States contribute 40% of the annual greenhouse gas (GHG) emissions, they are the single largest target for GHG reduction. By generating both electricity and heat at the point of use in a building, an increase in end use fuel efficiency (generally 30-40%) is achieved. The Tecogen family of 7.4L naturally-aspirated V8 natural gas fired engine products can provide electricity and heat efficiently with insignificant emissions.

7. References

Source Test Report, Emissions Testing of the Internal Combustion Engine (IEC) for NO_x, CO, SO₂, O₂, CO₂, PM, and VOC, prepared by Almega Environmental & technical Services, Huntington beach, CA (September 1, 2011).

APPENDIX A

Sampling and Analytical Procedures

Appendix A - Sampling and Analytical Procedures

Test measurements were performed according to sampling and analysis procedures promulgated by the South Coast Air Quality Management District (SCAQMD), California Air Resources Board (CARB), or US Environmental Protection Agency (EPA). The sampling and analysis procedures used for this test program are summarized below. Any modifications or deviations not addressed herein are discussed in Section 4 of this report.

- A.1 EPA Methods 1-4– Determination of Stack Gas Volumetric Flow Rate, Molecular Weight, and Moisture Content
 - A.1.1 EPA Method 1A – Sampling Traverse Points
 - A.1.2 EPA Method 2C – Stack Gas Flow Rate
 - A.1.3 EPA Method 3A – Stack Gas Molecular Weight
 - A.1.4 EPA Method 4 – Stack Gas Moisture Content
- A.2 EPA Instrumental Analyzer Methods (M7E, M10, & M3A) – Continuous Monitoring of Gaseous Emissions, CEMS
- A.3 EPA Method 5 – Particulate Matter
- A.4 SCAQMD Method 6.1 – SO₂ Emissions
- A.5 SCAQMD Method 25.3 – VOC, as TGNMO

A.1 EPA Methods 1-4 – Determination of Stack Gas Volumetric Flow Rate, Molecular Weight, and Moisture Content

The fuel gas flow characteristics (i.e. flow rate, molecular weight, and moisture content) were determined according to EPA Methods 1 through 4. The testing was conducted as follows:

A.1.1 Sampling and Velocity Traverse

The number and location of traverse points were determined according to EPA Method 1 based on the physical dimensions of the sampling location and process parameters. In principle, the stack cross-section is divided into equal areas, each of which is represented by a “traverse point”. Generally, the number of traverse points diminish as the flow profile at the sampling location becomes uniform. In most cases, the maximum number of sampling points is 24 for particulate testing and 16 for velocity traverses. Fewer traverse points are permitted as described in the method. Since the stack diameter was 6” and the sampling location met the 2/8 duct diameter criteria, EPA Method 1A was used and total of 8 traverse points were utilized for PM and stack flow rate sampling purposes.

A.1.2 Stack Gas Velocity and Flow Rate

The velocity and volumetric flow rate of the stack gas is determined according to EPA Method 2C for small stacks (6” diameter). In this method, the velocity head (differential pressure) and temperature are measured at the required traverse points. The stack gas differential pressure head

was determined using a Standard type pitot tube and inclined liquid manometer. The temperature was measured using a type "K" thermocouple and digital temperature readout.

Prior to testing, the measurement system was set-up and leak-checked. Then the velocity head and temperature were recorded at predetermined traverse points. After the last traverse was completed, the system was again leak-checked. After completion of the traverse, the static pressure in the stack was determined in the centroid of the stack. The stack gas velocity was calculated using the velocity head, and stack gas temperature, pressure and molecular weight.

QA/QC for the method included field performance checks, and periodic calibrations of test equipment including the pitot tube, differential pressure gauge, TC and TC-readout. A swirl check was also performed to assess cyclonic flow.

A.1.3 Stack Gas Molecular Weight

The stack gas molecular weight (MW) was calculated based on the fraction of its major constituents including: oxygen (O₂), carbon dioxide, (CO₂), nitrogen (N₂), carbon monoxide (CO), and water (H₂O). The dry MW was calculated based on the partial fractions of O₂, CO₂, N₂, and CO. The O₂ and CO₂ fractions were determined by CEMS (Method 3A) and the balance was assumed to be N₂ and CO. The wet MW was calculated based on the fractions of dry gas and water vapor. The dry and wet MW was calculated according to the following equations:

$$MW_{\text{DRY}} = 0.32 \times \%O_2 + 0.44 \times \%CO_2 + 0.28 \times (\%N_2 + \%CO)$$

$$MW_{\text{WET}} = 0.18 \times \%H_2O + MW_{\text{DRY}} \times (1 - \%H_2O/100)$$

where: MW_{DRY} = stack gas molecular weight, dry-basis

MW_{WET} = stack gas molecular weight, wet-basis

0.32 = molecular weight fraction for O₂

0.44 = molecular weight fraction for CO₂

0.28 = molecular weight fraction for N₂ and CO

0.18 = molecular weight fraction for H₂O (water vapor)

%X = fraction of X in stack gas, dry basis, where X = O₂, CO₂, N₂, CO

%H₂O = fraction of water vapor in stack gas, wet-basis

A.1.4 EPA Method 4 – Stack Gas Moisture Content

The stack gas moisture content was determined according to EPA Method 4. In this method, water vapor is collected in a condenser while the dry stack gas volume is measured using a dry gas meter. The volume of water vapor was calculated from the amount of water condensed and the total gas volume was the sum of water vapor plus dry stack gas. The moisture content was determined as a fraction of the total wet stack gas volume. The following calculations were used.

$$B_{WS} = \frac{V_{W,Std}}{V_{M,Std} + V_{W,Std}}$$

$$V_{W,Std} = K_1 \times V_{H_2O}$$

$$V_{M,Std} = T_{Std}/P_{Std} \times Y_M \times V_M \times P_M/T_M$$

where:

- B_{WS} = Fraction of water vapor in stack gas
- $V_{W,Std}$ = Volume of water vapor (scf)
- $V_{M,Std}$ = Volume of stack gas sampled (dscf)
- K_1 = Unit volume of water vapor (0.04707 scf @68°F or 0.0464 scf @60°F)
- T_{Std} = Standard Temperature (528°R or 520°R)
- P_{Std} = Standard Pressure, 29.92 in. Hg
- Y_M = Dry gas meter calibration factor
- V_M = Measured volume of stack gas sampled
- P_M = Dry gas meter pressure (in. Hg)
- T_M = Dry gas meter temperature (°R)

Moisture content was determined simultaneously with the isokinetic sampling of particulate matter and reported moisture is based on SCAQMD Method 6.1 sampling train.

A.2 EPA Instrumental Analyzer Methods (M7E, M10, and M3A) - Continuous Monitoring of Gaseous Emissions, CEMS

In these methods, gaseous components of the stack gas (e.g. NO_x, O₂, CO₂, CO) are measured continuously according to Instrumental Analyzer Methods such as M7E for NO_x, M10 for CO and M3A for O₂ and CO₂ using Almega's mobile continuous emissions monitoring system (CEMS). Figure A-1 is a schematic of Almega's CEMS.

The CEMS extracts and conditions a representative stack gas sample and analyzes the gas using one or more analytical instruments. The extraction and conditioning system consists of a stainless steel heated probe, a short heated TFE sample line, a conditioning system, a TFE-diaphragm pump and a TFE transport (sample) line. The sample conditioning system, consisting of water knockout impingers and/or a thermoelectric condenser, removes moisture before the gas

is delivered to the analyzers. Sample flow and delivery are controlled using a flow control panel that includes valves, pressure gauges, and flow meters (rotameters). The flow control panel allows the user to deliver sample gas to any and all instruments. Instrument readings were recorded using a real-time strip chart and an electronic data acquisition system (DAS). Other pertinent data such as calibration gas cylinder numbers and concentrations, test location, dates, times, and operator identification are also recorded on the strip chart and on the field data form.

Sampling included pretest and post-test bias checks for each sampling run. Raw concentration data were corrected for sampling system bias according to Method 7E using the following equation:

$$C_{\text{CORR}} = C_{\text{MA}} \times \frac{(C_i - \text{BIAS}_{\text{ZERO}})}{(\text{BIAS}_{\text{SPAN}} - \text{BIAS}_{\text{ZERO}})}$$

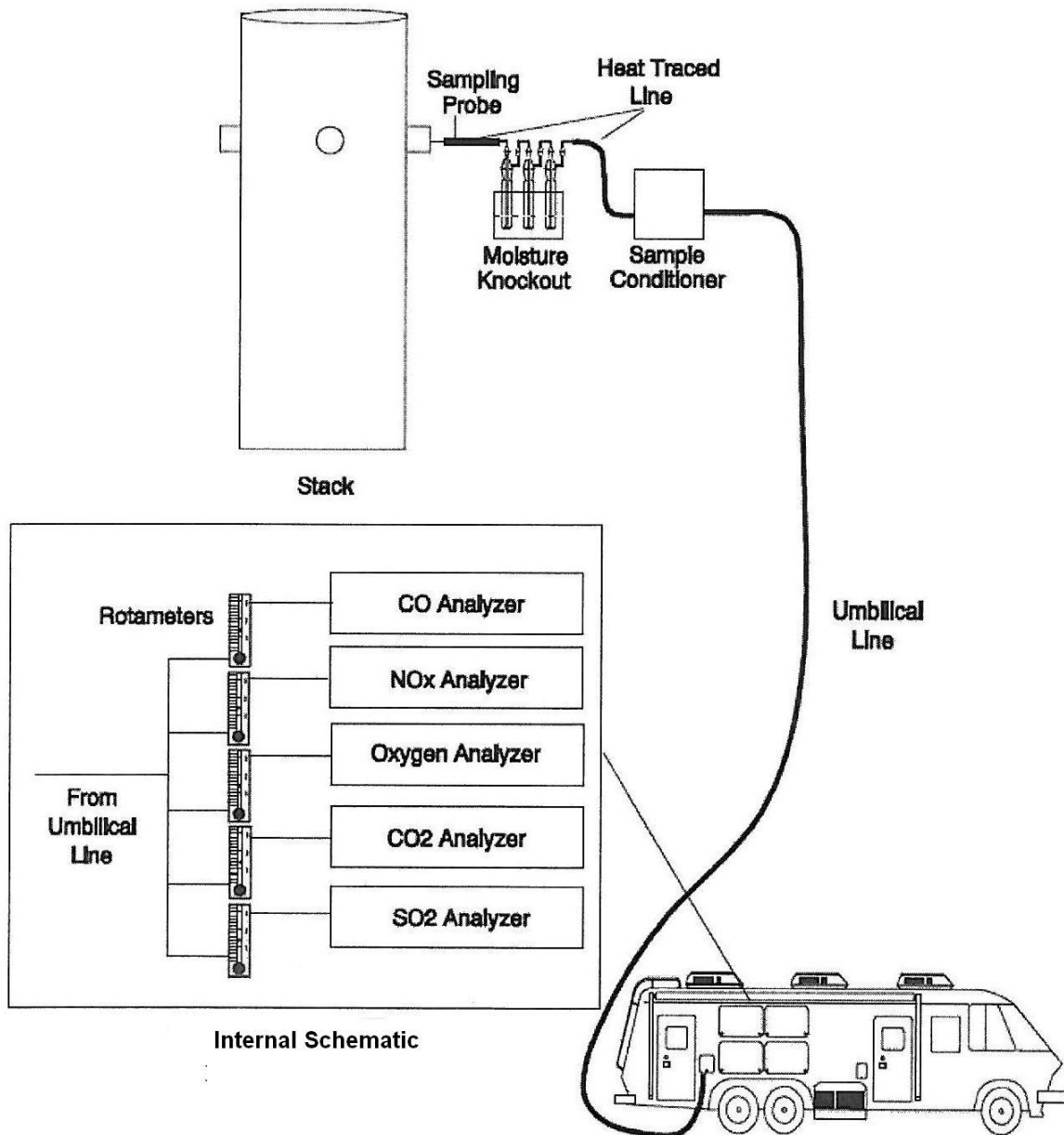
Where: C_{CORR} = Concentration, corrected for drift and bias
 C_i = Average measured concentration (raw value)
 $\text{BIAS}_{\text{ZERO}}$ = Average instrument response during zero bias check
 C_{MA} = Certified concentration of applicable span gas
 $\text{BIAS}_{\text{SPAN}}$ = Average instrument response during span bias check

The following QA/QC activities were performed during testing.

- Prior to testing, each individual analyzer was calibrated (adjusted) by introducing zero, hi-span and mid-span gases directly into each analyzer and by making corresponding adjustments.
- Prior to testing, calibration error, linearity and system bias checks were performed on each analyzer. Calibration error and linearity checks were performed by injecting known calibration gases directly to each instrument. Injecting calibration gases at the sampling-probe/junction or at the sampling probe tip performs system bias checks.
- The system response time for each parameter was determined at the moment when the calibration gas for the bias check reached 95% of its expected concentration value.
- Calibration gases used to span instrumentation conform to EPA Protocol-1. Certificates of analysis for calibration gases were included in the report.
- NO₂-to-NO conversion efficiency (CE) check was performed according to the procedure in Method 7E and the results of the CE check were included in the report. An NO₂ gas concentration used for converter efficiency tests was lower than 40-60 ppmv as specified in Method 7E to comply with the SCAQMD NO₂ converter test range.
- Interference test was conducted on each analyzer and test results were included in the report.

- A non-standard calibration gas value was generated using Almega's STEC "gas divider". The gas divider was field-certified according to EPA Method 205 "Verification of the Gas Dilution System for Field Instruments Calibration" and the certification data were included in the report.

Figure A-1. Continuous Emissions Monitoring System



A.3 EPA Method 5 – Total Particulate Matter

Particulate matter was withdrawn isokinetically from the source and collected on a filter maintained at a temperature in the range 120 ± 14 °C (248 ± 25 °F). Additionally, the sampling component upstream of the filter (the front half) was collected and extracted with acetone.

A series of preliminary measurements were made prior to conducting the particulate test. EPA Methods 1A, 2C, 3A and 4 were performed to determine location and number of traverse points, average gas velocity, molecular weight, and moisture content, respectively. The results of these measurements were used to determine the appropriate nozzle size for isokinetic sampling.

Figure A-2 shows a schematic of the sampling train used for EPA Method 5. The sampling train consists of a stainless steel nozzle, heated probe and filter, a set of glass impingers, umbilical line, a vacuum pump, dry gas meter, and calibrated orifice. Impingers #1 and #2 in the absorption train are charged with 100 ml of distilled water, impinger #3 is left empty, and impinger #4 is filled with approximately 200 g of silica gel. The probe is brushed out and rinsed with acetone. The filter is tarred and placed in the filter holder. The sampling apparatus is sealed and transported to the sampling site where it is assembled and leak tested at approximately 15 inches of mercury (Hg.) vacuum.

Then, after the initial gas meter reading was recorded, the vacuum pump was started and adjusted to obtain an isokinetic sample rate. A complete traverse was performed for each test. Stack gas temperature, velocity pressure (dP), meter temperature, gas volume, meter pressure, filter temperature and sampling vacuum were monitored and recorded at each point.

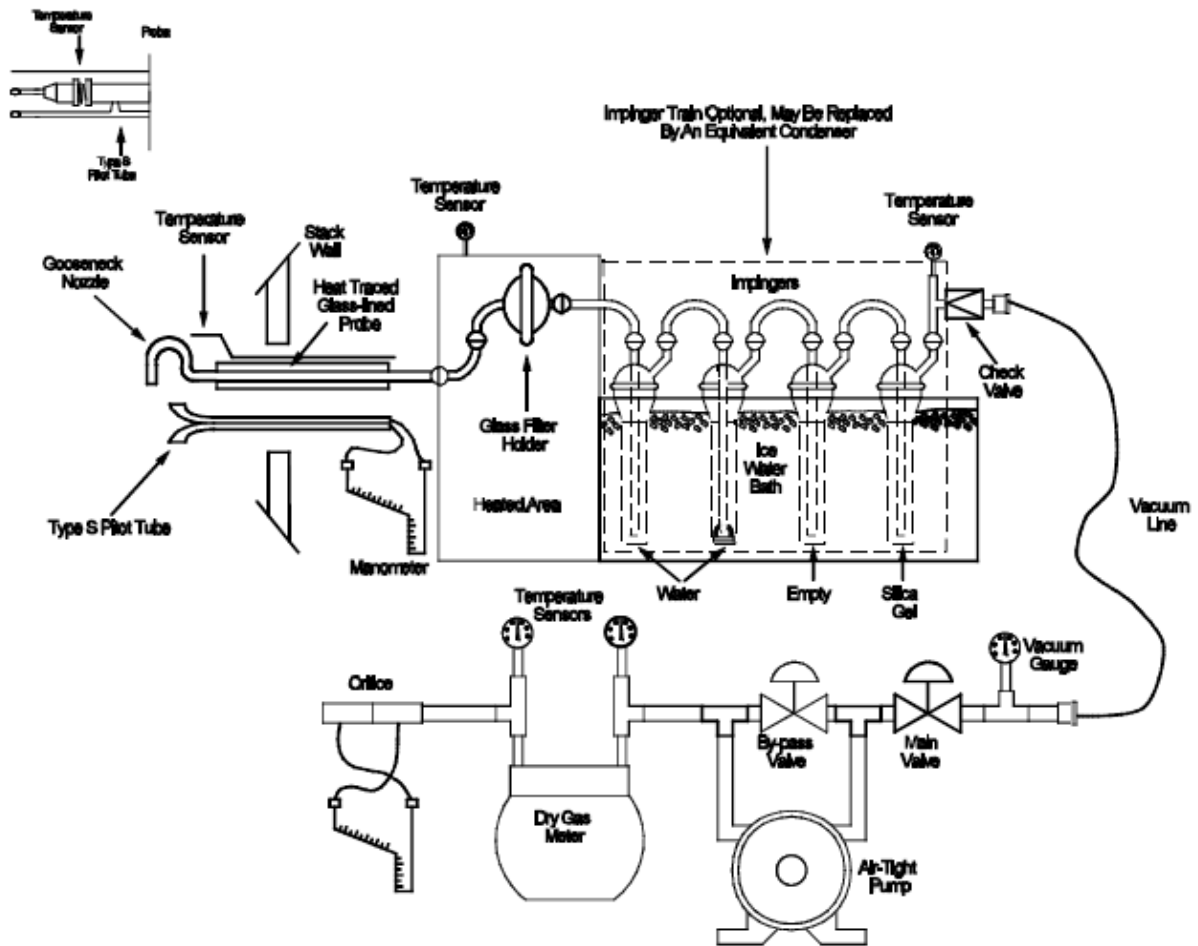
Upon completion of sampling, the apparatus was leak checked at a vacuum greater than the highest vacuum observed during testing. After the leak rate was recorded, the apparatus was disassembled, sealed and transported to the laboratory for recovery. The probe, nozzle and filter housing were washed as instructed per EPA Method 5. The wash fluid was subsequently transferred to clean, labeled bottles, where the fluid level was appropriately marked.

The filter and any loose particulate were carefully removed from the filter holder with tweezers. The filter was placed into a labeled Petri dish and secured until analysis. The nozzle, probe and filter housing were rinsed and brushed until the acetone rinse showed no visible particles. The sample fractions were combined, bottled, labeled, and fluid levels marked, for transportation to the Almega laboratory for analysis.

Analysis included probe and front half of the filter holder and the filter portion. The water gain in the impingers (condensable fraction) was weighed on a digital scale in order to determine percent moisture only. No particulate analysis was conducted on the back half portion.

The sample was prepared as per the method and analyzed by Almega's in-house laboratory.

Figure A-2 Sampling Apparatus for Particulate Matter



A.4 SCAQMD Method 6.1 – Sulfur Dioxide Emissions

The sampling train, Figure A-3, consists of a heated glass-lined probe, a heated box (above the dew point but below 200°F) with a filter capable of removing sulfuric acid and other sulfates, an absorption train, and a meter box assembly. The absorption train was charged with freshly prepared chemicals. The absorption train consists of six impingers as shown in Figure A.3. But actual sampling included only five impingers as the purpose of this test was to determine only SO₂ emissions and therefore the first impinger with 200 ml of 80% 2-propanol was omitted in this sampling. For this sampling, first and fourth impingers were left empty. Second and third impingers contained 100 ml of 3% H₂O₂ solution, and the fifth impinger was filled with known weight of silica gel. The glass-lined probe was brushed out and rinsed with distilled water prior to sampling. The sampling train was sealed and transported to the sampling site where it was assembled and leak tested at around 16 inches of mercury (Hg) vacuum. Since the PM rate was anticipated to be extremely low and sulfuric acid mist was not expected in the stack gas, one (1) 240 minute single point sampling was conducted, in lieu of multiple runs, in order to increase the amount of sample that could be collected and analyzed.

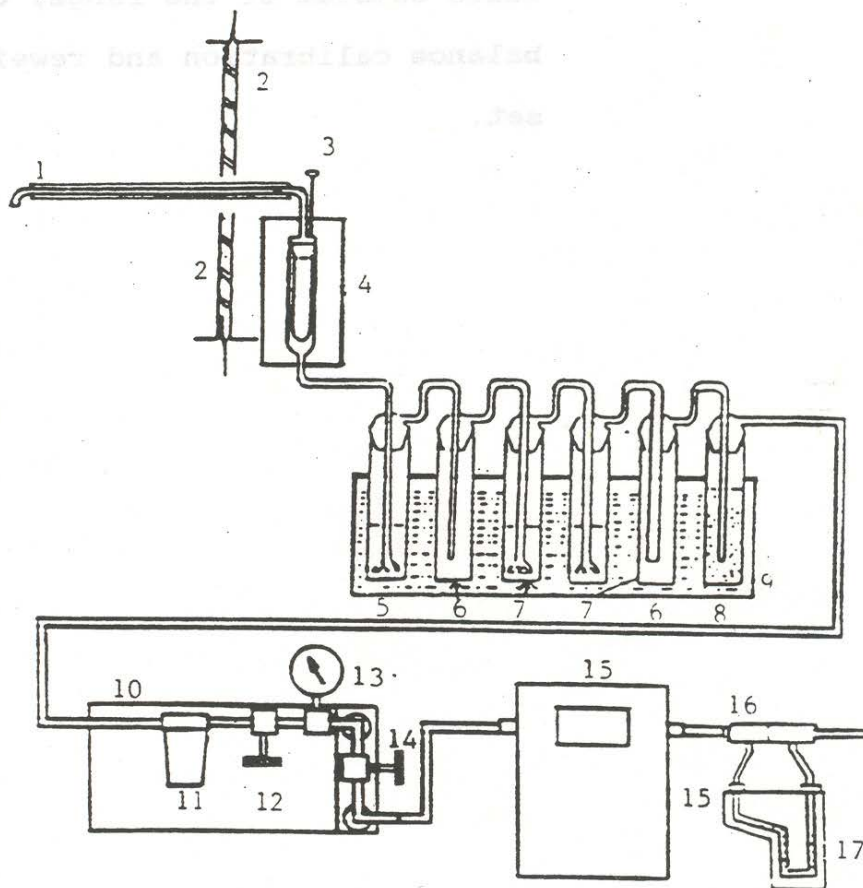
Upon completion of sampling, the apparatus was leak checked at a vacuum greater than the highest vacuum observed during the test run. After the post leak check, the ice-bath was drained and the probe disconnected from the filter holder and the filter holder from the remainder of the train. The filter was recovered in a Petri dish. All five impingers were disconnected and weighed separately and the contents were transferred to sample container #1 (silica gel was only weighed for moisture determination). All five impingers and connecting glassware were rinsed at least three times with water and transferred into container #2. The sample containers were sealed and marked before being transported to the laboratory. In the laboratory, both the filter and H₂O₂ impinger's fraction were analyzed for sulfate following the procedures specified in the method. Test results were calculated as follows:

Sulfur Dioxide Concentration, as SO₂:

$$\text{SO}_2 \text{ ppm} = (835.3) (C) / (V_m)(64)$$

Where: C = Sulfur dioxide in H₂O₂, mg
V_m = Corrected gas volume metered, dscf

Figure A-3 Sampling Train for Sulfur Oxides



- | | |
|---|--|
| 1. Heated Glass Probe | 9. Ice Bath |
| 2. Stack Wall | 10. Sealed Pump (Leak Free) |
| 3. Dial Thermometer | 11. Filter for Pump |
| 4. Whatman Thimble Filter
(Inside Hot Box) | 12. Metering Valve |
| 5. Impinger with 200 ml
Isopropanol | 13. Vacuum Gauge |
| 6. Empty Bubbler | 14. By-pass Valve |
| 7. Impinger with 100 ml H_2O_2 (3%) | 15. Temperature Compensated
Dry Gas Meter |
| 8. Bubbler with Silica Gel | 16. Orifice |
| | 17. Orifice Inclined Manometer |

A.5 SCAQMD Method 25.3 – VOC as TGNMO

This method applies to the measurement of low-concentration (≤ 50 ppmv) Volatile Organic Compounds (VOC) or total gaseous non-methane organics (TGNMO) in source emissions. In this Method, gaseous samples are withdrawn from the gas stream at a constant rate through duplicate chilled condensate traps and collected in evacuated sample tanks. The sampling system is depicted in Figure A-4. Each sampling train (there are two) consists of an in-stack filter (optional), sample probe, water-chilled mini-impinger, a flow control system, and an evacuated sample tank. The flow controller incorporates a combination vacuum/pressure gauge, which was connected directly to the canister. The TGNMO is determined by combining the analytical results obtained from independent analyses of the condensate traps (condensable fraction) and the sample tanks (gaseous fraction).

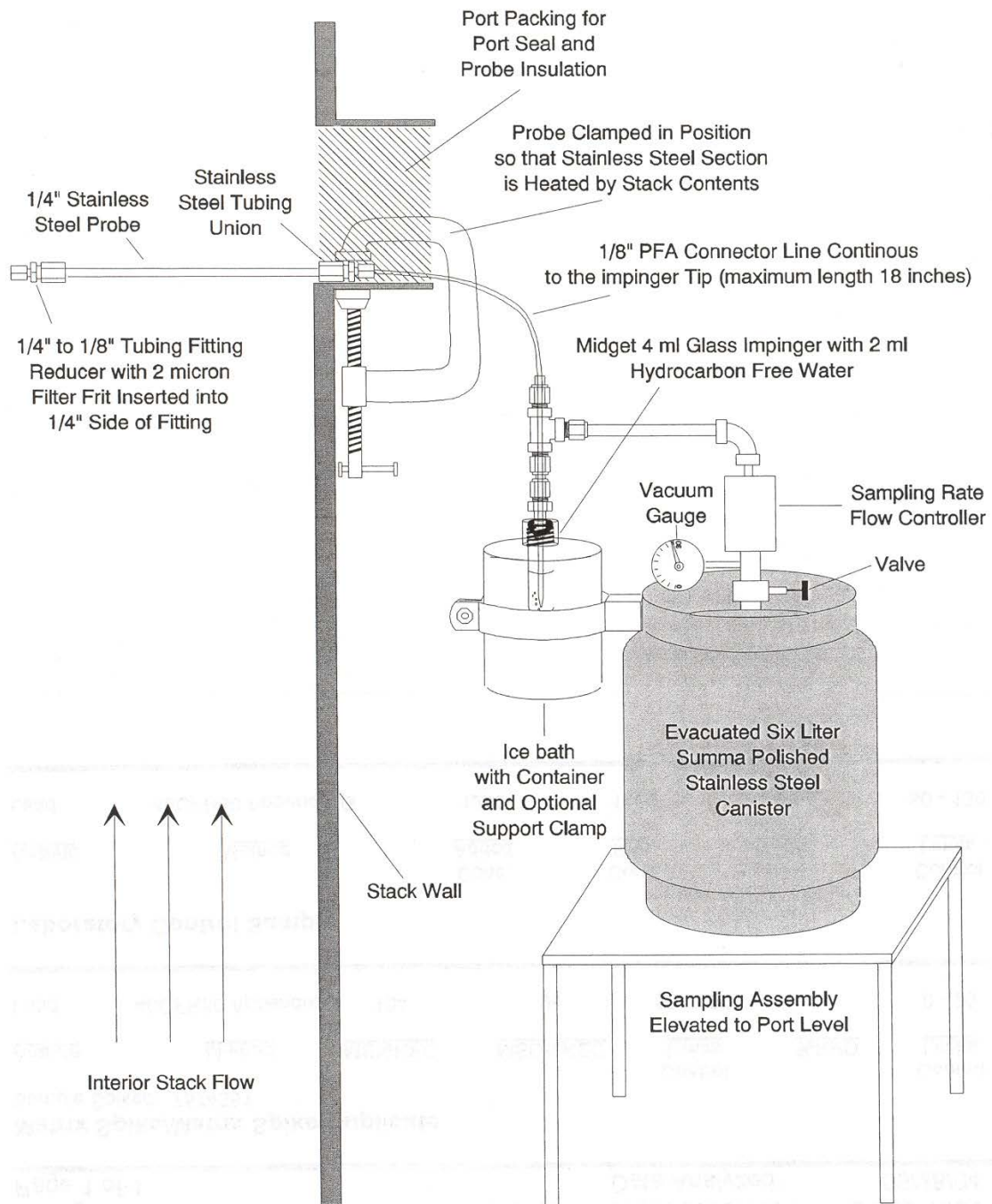
Prior to testing, the sampling system is pre-cleaned and evacuated in preparation for sample collection. On-site, the sampling system is leak-checked and the impingers are placed in an ice-slurry (the impingers are chilled for at least 30 minutes prior to sampling). Then the sample probe is placed in the stack, facing downstream to prevent collection of particulate matter. Pretest data is recorded and the sample valve is opened. The flow controller is based on a critical orifice that is preset to flow at a rate of 80-cc/min \pm 15%. Periodically, sampling train readings (i.e. tank vacuum) are recorded on the field data sheet. Sampling is stopped when one hour has elapsed and/or and tank vacuum reaches 2 inches as indicated by the vacuum gauge. Then, the sampling train is removed from the stack and a leak check is performed. Samples are logged in and delivered to the laboratory for analysis.

The analytical system consists of two major sub-systems: a total organic carbon (TOC) analyzer capable of differentiating between total carbon (TC) and inorganic carbon (IC) and a non-methane organics (NMO) analyzer. The NMO analyzer is a gas chromatograph (GC) with back flush capability for NMO analysis and is equipped with an oxidation catalyst, reduction catalyst, and flame ionization detector (FID). The system for the recovery and conditioning of the organics captured in the condensate trap consists of a heat source, oxidation catalyst, non-dispersive infrared (NDIR) CO₂ analyzer and an intermediate collection vessel (ICV). Analyses are performed as follows.

NMO collected in the water impinger are analyzed in the TOC analyzer. The TOC analyzer determines both TC and IC; the TOC is calculated as the difference between TC and IC.

The organic content of the sample fraction collected in the sampling tank is measured by injecting a gas sample into the GC to separate the NMO from carbon monoxide (CO), CO₂ and CH₄. The NMO are oxidized to CO₂, reduced to CH₄, and measured by the FID. In this manner, the variable response of the FID (associated with different type of organic compounds) is eliminated. The sampling apparatus and sample analysis services were provided by Omega, which is a SCAQMD-approved laboratory.

**Figure A-4. Sampling Apparatus for TGNMO per SCAQMD Method 25.3
(Figure shows one train – actual method runs in duplicate simultaneously)**



APPENDIX B

Quality Assurance and Quality Control

Appendix B- Quality Assurance and Quality Control

Almega applies stringent quality assurance and quality control (QA/QC) procedures to ensure the validity of measurements for all test methods. The following section discusses general and project-specific QA/QC measures.

B.1 General QA/QC

Almega's QA/QC procedures follow guidelines from the "Quality Assurance Handbook for Air Pollution Measurement Systems," Volume I through III; procedures for pretest preparation and calibration of sampling equipment are followed. Standardized written procedures, calculator programs, and computer spreadsheets are used for test planning, pre-survey, equipment checklist, preliminary calculations, testing, data analysis, and reporting. Pretest equipment preparation and maintenance include organization of the following equipment prior to testing:

- Mobile Reference Method (RM) CEM test van: Check fluids, fuel, mechanical conditions, verify operation of CEM instruments, sample lines and sample conditioner prior to the date of the source test.
- Sampling Equipment: Check meter boxes, pitot tubes, manometers and thermocouples to ensure that they are in good working condition and in proper calibration. Pre-clean sampling trains and seal all openings prior to use.

Calibrations are performed in accordance with Chapter III of the SCAQMD Source Test Manual (March 1989). Table B-1 shows the test equipment calibration schedules. Table B-2 shows the test equipment maintenance schedules.

B.2 Project-Specific QA/QC

This project included specific QA/QC activities required to validate the test results. These QA/QC activities are based on the test methods discussed in Appendix A and generally acceptable test procedures. Reference Methods used for source testing are promulgated by the South Coast Air Quality Management District (SCAQMD), the California Air Resource Board (CARB), or the US Environmental Protection Agency (EPA). Any deviations from published Methods are approved in advance by the regulatory agency (i.e. SCAQMD), prior to implementation if possible. Project-specific QA/QC activities and results that may impact test results are discussed in Section 4.

Table B-1 Test Equipment Calibration Schedule

Equipment	Calibration Period	Standard or Method of Calibration
Thermocouples	6 Months and 2 Months	Mercury Thermometer, three point (ice, boiling water, hot oil)
Dry Gas Meters	6 Months and 2 Months	Critical Orifice
Field Barometers	6 Months, Check prior to usage	Mercury Barometer
S-Type Pitot	6 Months Check prior to usage	EPA Method 2, Measure physical configuration. Reshape pitot tips or calibrate if configuration does not meet the limits.
Pressure gauges	6 Months	Five-point calibration against manometer
	2 Months	Three-point check
Temp. Meters	6 Months	Precision Potentiometer
CEM Systems	Bimonthly, or as needed	Specified by Manufacturer

Table B-2 Test Equipment Maintenance

Equipment	Check For	Correction	Frequency
CEM Systems	<i>Absence of malfunction, noise, drift, conversion efficiency for NOx anlzr.</i>	<i>As required by the manufacture, or depending on performance</i>	<i>Bimonthly</i>
Pumps	Absence of leakage, flow, proper vacuum	Replace parts, inspect, clean	300 hours of usage
Flow Devices	Levelling, zeroing, obstruction, deformation	Clean, replace, or re-calibrate	300 hours of usage
Calibration Gases	Expiration date, tank pressure	Re-certify, order new gases	2 months and prior to field testing
Regulators	Malfunction, Gauge precision	Repair or replace	3 months and prior to field testing
Gas Divider	Malfunction, precision	Repair or replace	Monthly and before field testing
Condensers	Leakage, temperature	Repair or replace	Monthly and before field testing
Heated lines	Leakage, temperature, cleanliness	Repair, replace, clean	Monthly and before field testing